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[54] **SYSTEM FOR CONTROLLING A VEHICLE TO SELECTIVELY ALLOW OPERATION IN EITHER AN AUTONOMOUS MODE OR A MANUAL MODE**

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[73] Assignee: **Caterpillar Inc.**, Peoria, Ill.

[21] Appl. No.: **299,447**

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[51] **Int. Cl.**[6] **G06F 165/00**

[52] **U.S. Cl.** **364/424.02**; 364/424.07; 318/591

[58] **Field of Search** 364/424.01, 424.02, 364/424.07, 426.04, 424.1, 449; 318/587, 591; 180/167, 168, 169; 348/114, 118, 119, 120

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PCT Appl. No. 90/07183; Int'l Pub. Date: Jun. 27, 1991; Int'l Pub. No.: WO 91/09275.

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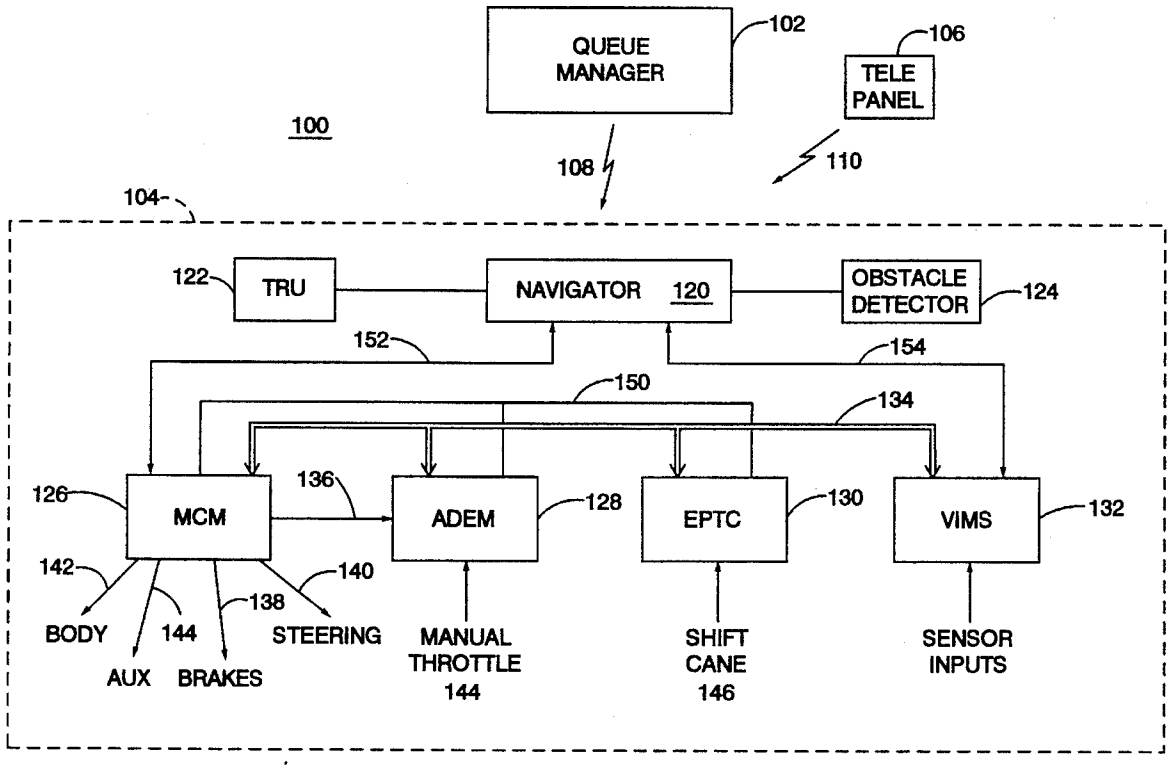
Attorney, Agent, or Firm—Sterne, Kessler, Goldstein and Fox

[57] **ABSTRACT**

A system for controlling autonomous operation of a vehicle in response to speed and steering angle request signals from a navigator allows manual operation of the vehicle. The system includes a machine control module, an engine control module, and a transmission control module. An auto/manual select signal indicates to the machine control module whether operation should be in a fully autonomous mode or a manual mode. In the autonomous mode, a navigator produces a speed request signal and a steering angle request signal for the vehicle. The machine control module receives the speed and steering angle request signals from the navigator. From these inputs, the machine control module produces an engine RPM (revolutions per minute) control signal for the engine control module, a transmission control signal for the transmission control module, a brake control signal, and a steering angle control signal. In the manual mode, the machine control module will not interfere with normal, manual (i.e., manned) control of all vehicle systems.

12 Claims, 6 Drawing Sheets



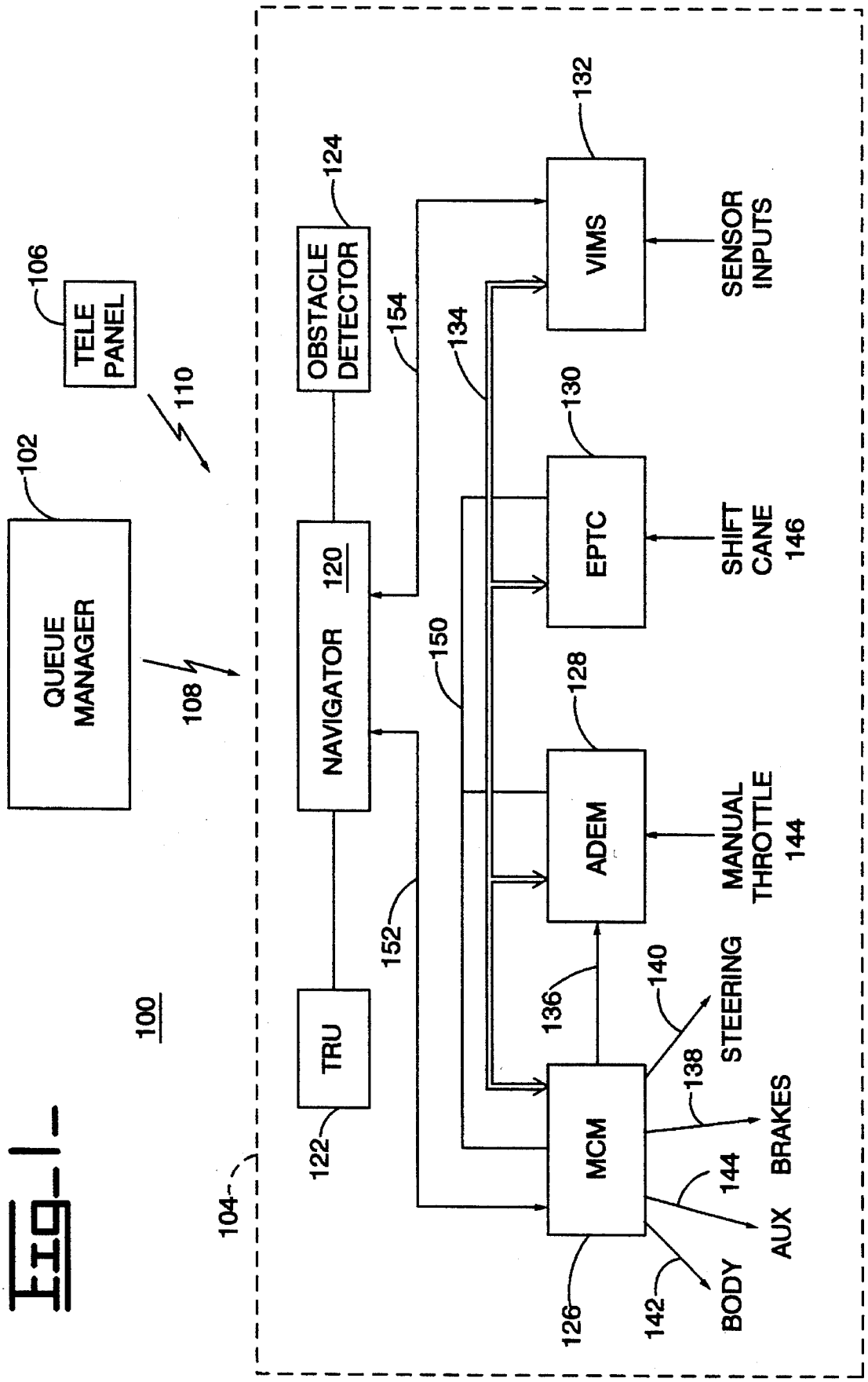

100
QUEUE MANAGER
102
108
TELE PANEL
106
110
104
NAVIGATOR 120
OBSTACLE DETECTOR
124
TRU
122
VIMS
132
SENSOR INPUTS
EPTC
130
SHIFT CANE 146
ADEM
128
MANUAL THROTTLE 144
MCM
126
STEERING
140
BRAKES
138
AUX
144
BODY
142
134
136
150
152
154

Fig. 1

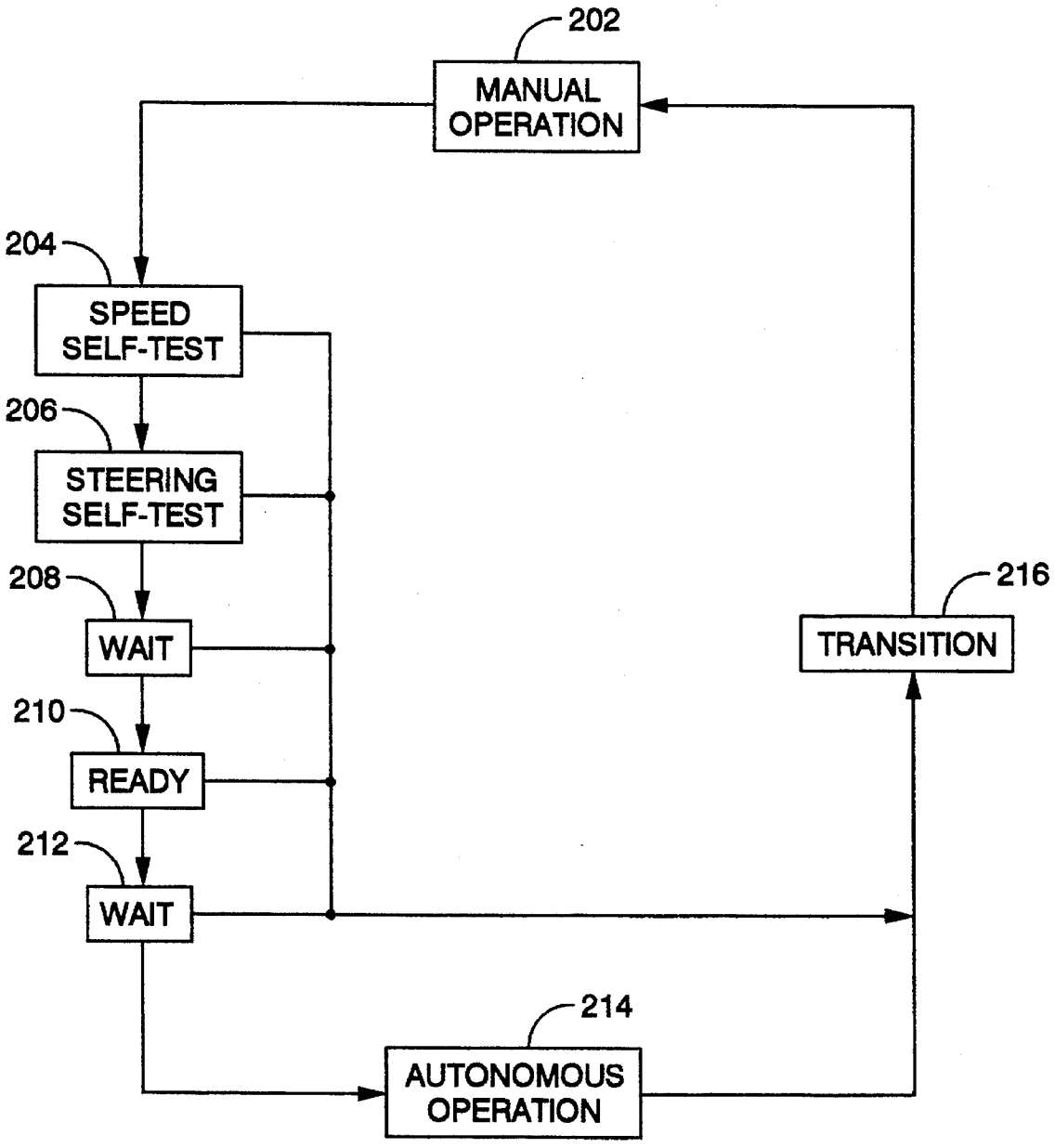

202
MANUAL OPERATION
204
SPEED SELF-TEST
206
STEERING SELF-TEST
208
WAIT
210
READY
212
WAIT
214
AUTONOMOUS OPERATION
216
TRANSITION

Fig_2_

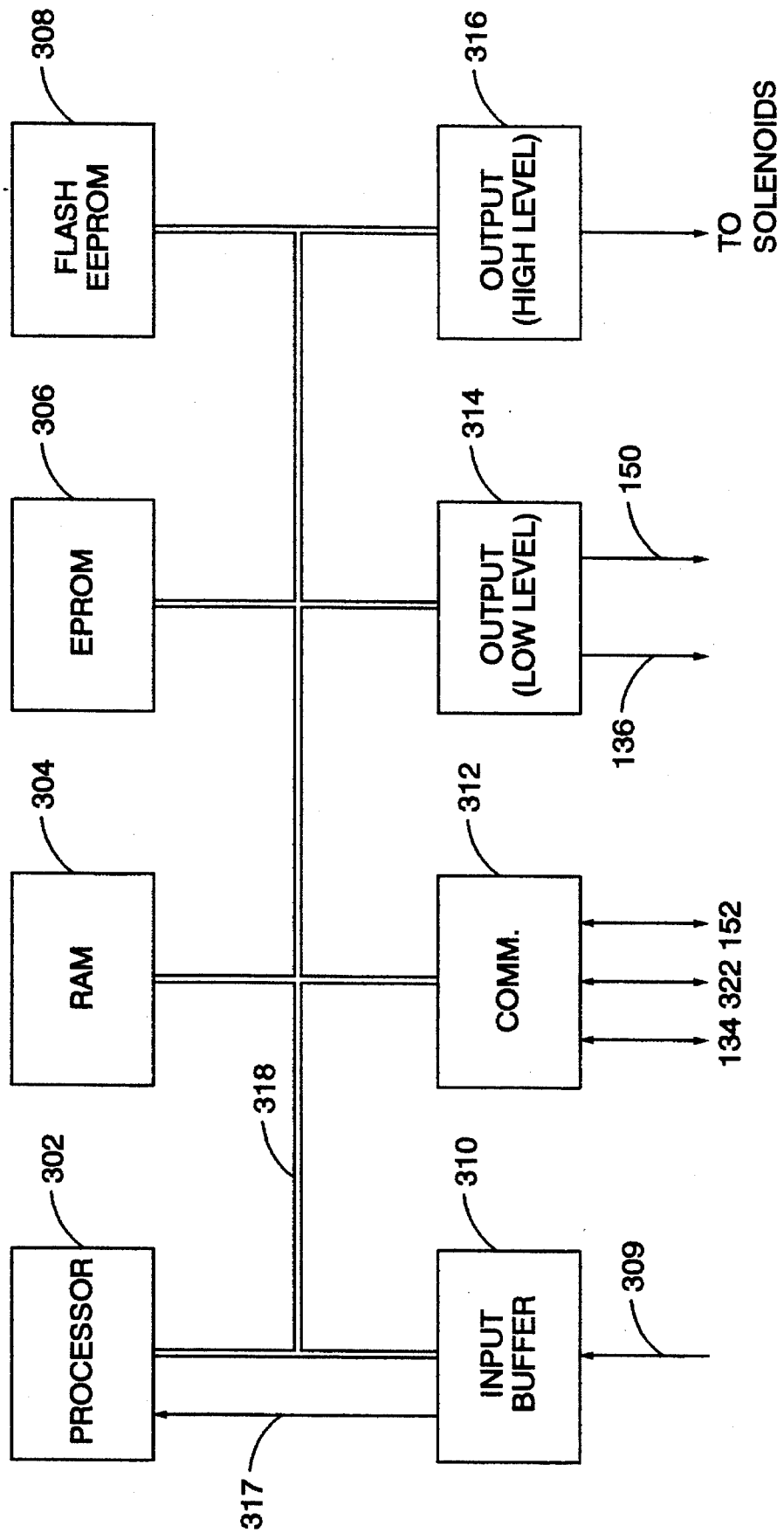

308
FLASH EEPROM
316
OUTPUT (HIGH LEVEL)
TO SOLENOIDS
306
EPROM
314
OUTPUT (LOW LEVEL)
150
136
304
RAM
312
COMM.
134 322 152
318
302
PROCESSOR
310
INPUT BUFFER
309
317
126

Fig-3-

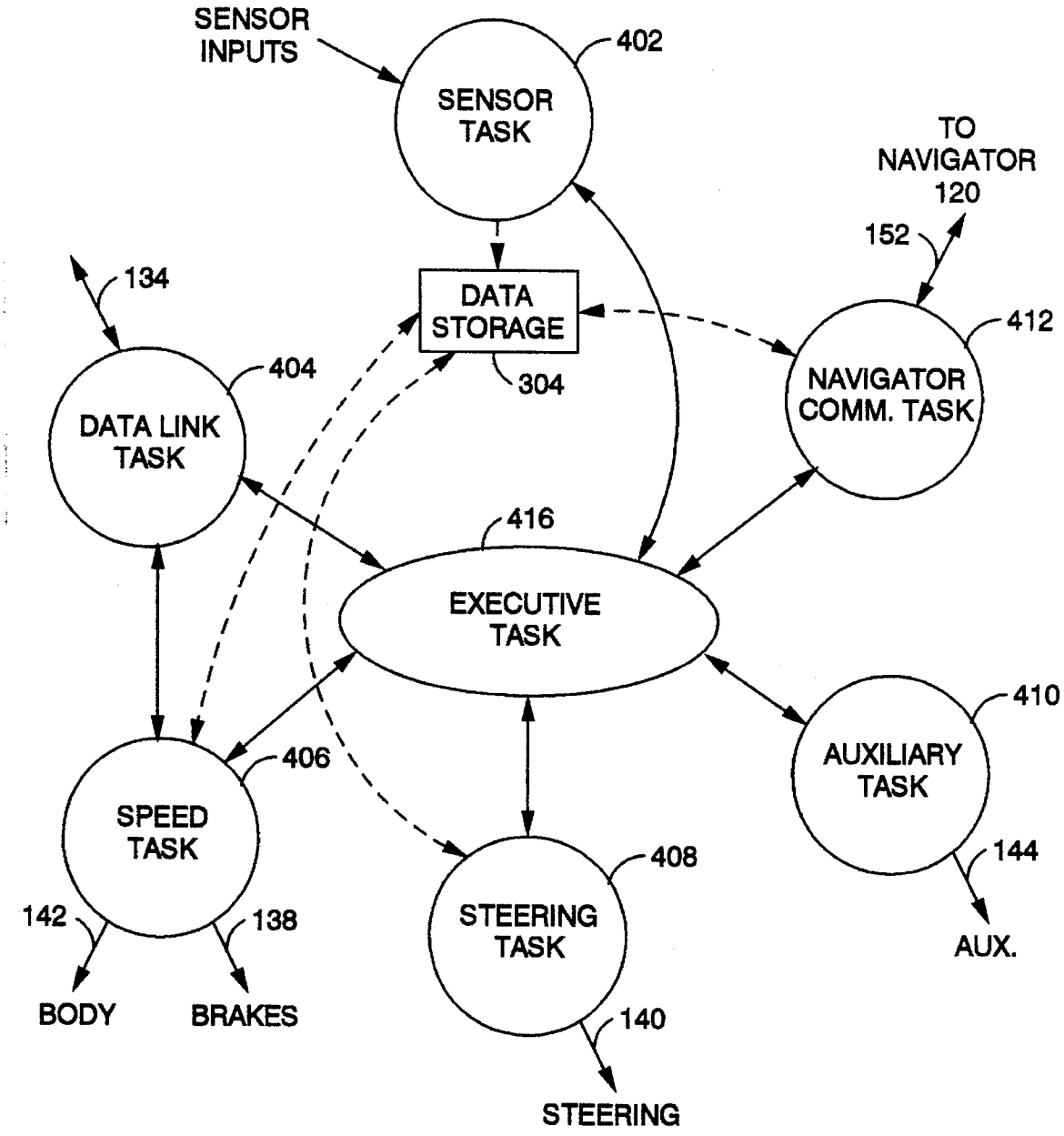

SENSOR INPUTS
SENSOR TASK
402
TO NAVIGATOR 120
152
134
DATA STORAGE
304
412
404
DATA LINK TASK
NAVIGATOR COMM. TASK
416
EXECUTIVE TASK
410
406
AUXILIARY TASK
SPEED TASK
408
144
142
138
STEERING TASK
AUX.
BODY
BRAKES
140
STEERING

Fig_4_

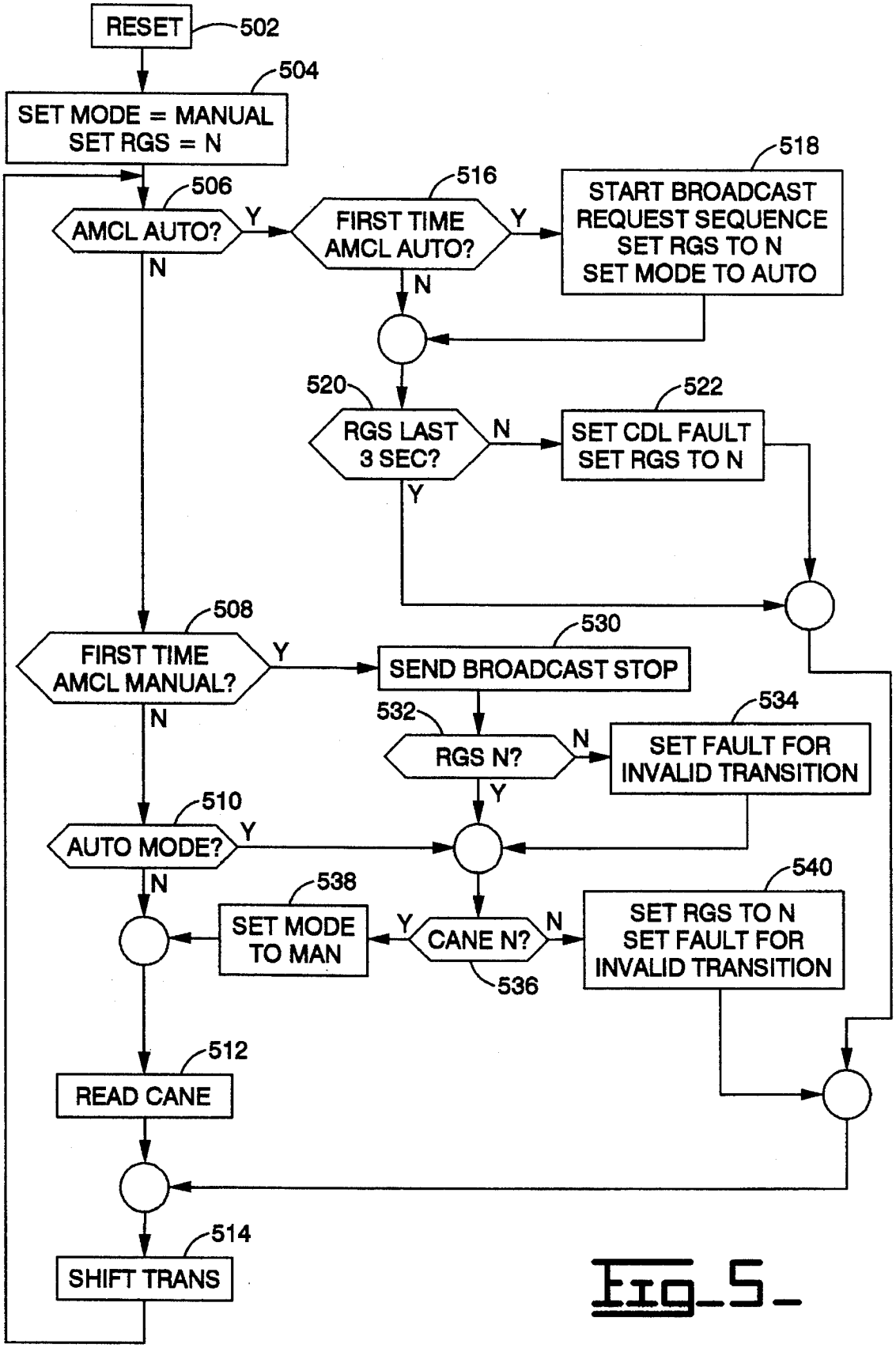

RESET
502
504
SET MODE = MANUAL
SET RGS = N
506
AMCL AUTO?
Y
N
516
FIRST TIME
AMCL AUTO?
Y
N
518
START BROADCAST
REQUEST SEQUENCE
SET RGS TO N
SET MODE TO AUTO
520
RGS LAST
3 SEC?
N
Y
522
SET CDL FAULT
SET RGS TO N
508
FIRST TIME
AMCL MANUAL?
Y
N
530
SEND BROADCAST STOP
532
RGS N?
N
Y
534
SET FAULT FOR
INVALID TRANSITION
510
AUTO MODE?
Y
N
538
SET MODE
TO MAN
Y
CANE N?
N
536
540
SET RGS TO N
SET FAULT FOR
INVALID TRANSITION
512
READ CANE
514
SHIFT TRANS

Fig_5_

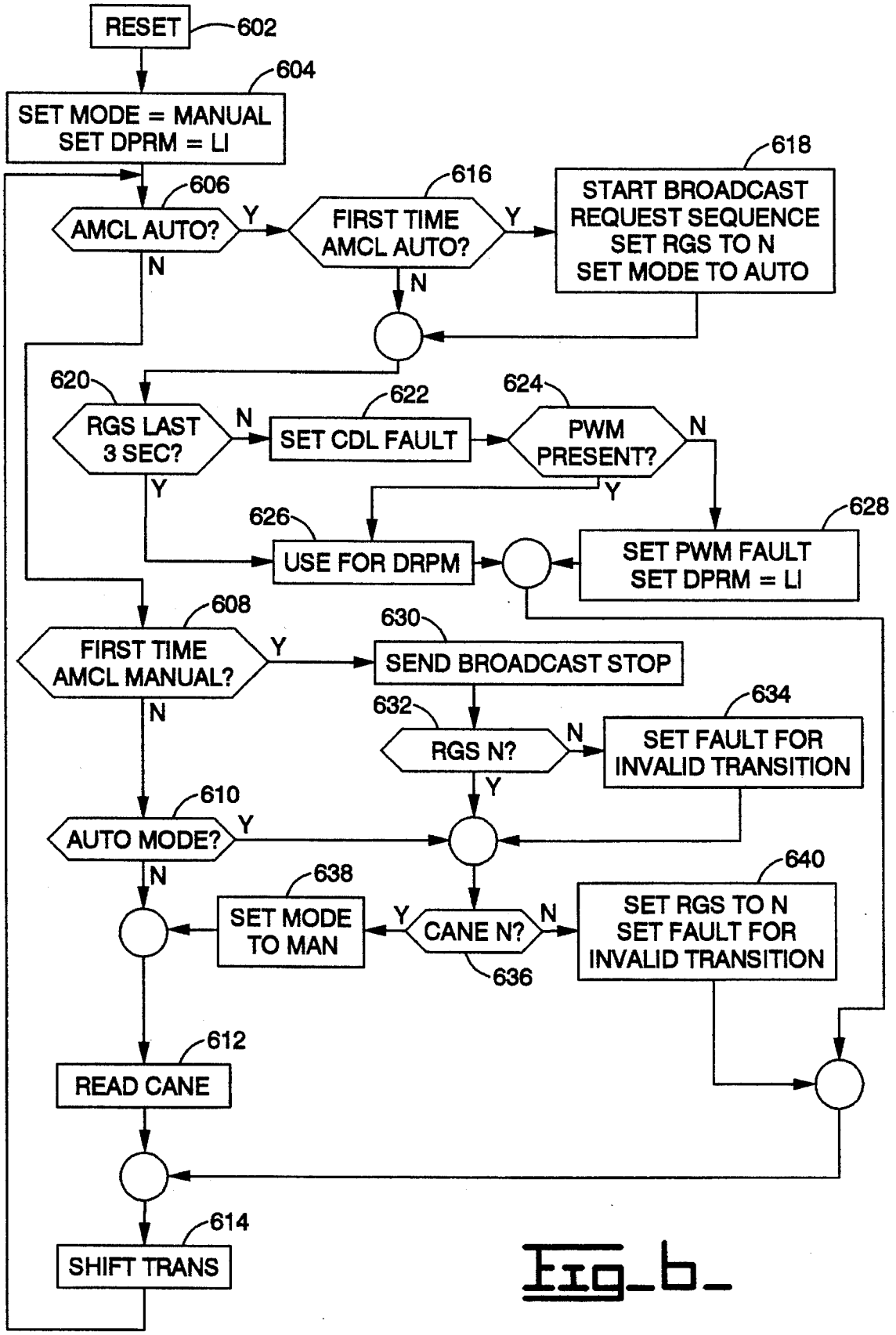

RESET
602
604
SET MODE = MANUAL
SET DPRM = LI
606
AMCL AUTO?
Y
N
616
FIRST TIME AMCL AUTO?
Y
N
618
START BROADCAST REQUEST SEQUENCE
SET RGS TO N
SET MODE TO AUTO
620
RGS LAST 3 SEC?
N
Y
622
SET CDL FAULT
624
PWM PRESENT?
N
Y
626
USE FOR DRPM
628
SET PWM FAULT
SET DPRM = LI
608
FIRST TIME AMCL MANUAL?
Y
N
630
SEND BROADCAST STOP
632
RGS N?
N
Y
634
SET FAULT FOR INVALID TRANSITION
610
AUTO MODE?
Y
N
638
SET MODE TO MAN
Y
CANE N?
N
636
640
SET RGS TO N
SET FAULT FOR INVALID TRANSITION
612
READ CANE
614
SHIFT TRANS

Fig_6_

SYSTEM FOR CONTROLLING A VEHICLE TO SELECTIVELY ALLOW OPERATION IN EITHER AN AUTONOMOUS MODE OR A MANUAL MODE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to the control of autonomous vehicles and, more particularly, to a system for controlling an autonomous vehicle which allows selective operation in either an autonomous mode or a manual mode.

2. Related Art

Caterpillar Inc. of Peoria, Ill., manufactures off-road mining vehicles. For example, the Caterpillar 777C is an off-road mining truck. The 777C includes sophisticated electronic monitoring and control systems. For example, an advanced diesel engine manager (ADEM) controls engine speed in response to input from an operator-controlled accelerator pedal; an electronic programmable transmission control (EPTC) assures that the transmission is in the proper gear; and a vital information management system (VIMS) monitors vehicle systems and provides status information to the driver/operator.

Commonly owned, U.S. Pat. No. 5,390,125, filed Feb. 18, 1993, "Vehicle Position Determination System and Method," the full text of which is incorporated herein by reference, discloses an autonomous vehicle system for use with a mining vehicle such as the 777C truck. What is needed is a means for integrating the commercially available electronic monitoring and control systems of a manned vehicle with an autonomous vehicle system such as that described in the '540 application to produce a vehicle which may be selectively operated in either a manual (i.e., manned) mode or an autonomous mode.

SUMMARY OF THE INVENTION

The invention is a system for controlling a vehicle, such as a mining truck, to selectively allow operation in either an autonomous mode or a manual mode. The system includes a machine control module, an engine control module, and a transmission control module. In the autonomous mode, a navigator produces a speed request signal and a steering angle request signal for the vehicle. The machine control module receives an auto/manual select signal from an operator and the speed and steering angle request signals from the navigator. From these inputs, the machine control module produces an engine RPM (revolutions per minute) control signal, a transmission control signal, a brake control signal, a steering angle control signal, and an auto/manual control signal.

The engine control module controls an RPM of the engine of the vehicle in response to the engine RPM control signal when the auto/manual control signal indicates autonomous operation. When the auto/manual control signal indicates manual operation, the engine control module controls engine RPM in response to manual input from an operator, i.e., from an accelerator pedal similar to those found in automobiles.

The transmission control module controls gear selection in a transmission of the vehicle in response to the transmission control signal when the auto/manual control signal indicates autonomous operation. When the auto/manual control signal indicates manual operation, the transmission control module controls gear selection in response to operator input, i.e., from a shift lever or cane.

In the preferred embodiment of the invention, the machine control module is a computer-based system including a navigator communications task, a sensor task, an executive task, a speed control task and a steering task. The navigator communications task receives the speed and steering angle requests from the navigator. The sensor task receives a measured steering angle, a measured speed and an auto/manual select signal from various switches and/or sensors. The executive task supervises operation of the other tasks and generates an auto/manual control signal in response to the auto/manual select signal. The steering task controls vehicle steering in response to the steering angle request signal and the measured steering angle.

The speed control task controls vehicle speed in response to the speed request signal and the measured speed by generating the engine RPM control signal, the transmission control signal and the brake control signal. The speed control task may control other vehicle functions. For example, it may control the position of a body or bed of a dump truck or the bucket of a wheel loader.

The machine control module further includes a data link task and an auxiliary task. The data link task communicates the engine RPM control signal to the engine controller and the transmission control signal to the transmission controller. The auxiliary task controls auxiliary functions on the vehicle, such as lights and horn.

The foregoing and other features and advantages of the invention will be apparent from the following, more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a high level block diagram showing the autonomous vehicle system of the invention;

FIG. **2** is a flow chart illustrating the steps involved in switching operation of a vehicle between manual and auto modes of operation;

FIG. **3** is a block diagram illustrating the structure of the machine control module of the invention;

FIG. **4** is a task diagram illustrating the operation and organization of the machine control module of the invention;

FIG. **5** is a flow chart illustrating auto and manual operation of an EPTC in accordance with the present invention; and

FIG. **6** is a flow chart illustrating auto and manual operation of an ADEM in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the invention is discussed in detail below. While specific part numbers and configurations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the invention.

The preferred embodiment of the invention is now described with reference to the figures where like reference numbers indicate like elements. In addition, the left-most digit of each reference number indicates the figure in which the number is first used.

System Overview

FIG. **1** is a high level block diagram showing an autonomous vehicle system **100**. Autonomous vehicle system **100** includes a fleet manager **102** and a vehicle control system **104**. System **100** may also include a tele-operation panel **106** as discussed in further detail below.

Fleet manager **102** is configured to manage a fleet of autonomous mining vehicles such as dump trucks. Fleet manager **102** acts like a foreman, assigning tasks to the mining vehicles and tracking their progress as they perform these tasks. Fleet manager **102** communicates with each vehicle via a radio link **108**. Each vehicle includes an on-board vehicle control system **104**. Vehicle control system **104** permits autonomous operation of the mining vehicle under the control of fleet manager **102**. Vehicle control system **104** includes a navigator **120**, a truck reference unit (TRU) **122**, an obstacle detector **124**, a machine control module (MCM) **126**, and advanced diesel engine manager (ADEM) **128**, an electronic programmable transmission control (EPTC) **130**, and a vital information management system (VIMS) **132**.

Navigator **120** receives instructions from fleet manager **102** via radio link **108**. The instructions include, for example, a work assignment or task. From the task, navigator **120** determines a route to be followed. The route may be, for example, a haul segment between an excavation site and a crusher site in an open pit mining operation.

TRU **122** determines the actual position of the vehicle using the global positioning system (GPS) and an inertial reference unit (IRU). Based on the actual position and the desired route, navigator **120** generates a desired steering angle and a desired speed for the vehicle. Obstacle detector **124** is a radar unit which scans the area in front of the vehicle for obstacles. When obstacle detector **124** detects an obstacle, it provides an indication that an obstacle is detected and/or the location of the obstacle to navigator **120**. Navigator **120** may then stop the vehicle or navigate around the obstacle.

Tele-operation panel **106** may be used to communicate, via radio signals as indicated at **110**, steer angle, speed and other commands directly to navigator **120** to allow remote control operation of the vehicle.

Examples of fleet manager **102**, tele-operation panel **106**, navigator **120**, TRU **122** (also known as a "vehicle positioning system") and obstacle detector **124** are described in detail in the '540 application which is incorporated by reference above. In addition, an example of tele-operation panel **106** is described in commonly owned, allowed copending U.S. patent application Ser. Appl. No. 08/299,448, titled "Remote Control System and Method for an Autonomous Vehicle," filed on even date herewith.

Navigator **120**, TRU **122** and obstacle detector **124** represent on-board intelligence for the vehicle which allows autonomous control commands to be generated in the form of the speed and steering angle request signals. Before autonomous operation can be achieved, however, these commands or requests must be serviced.

The present invention services the steering and speed requests, among others, to achieve autonomous (or simply "auto") operation. MCM **126** receives the steering and speed requests from navigator **120** over a data bus **152**. Over this same data bus, MCM **126** provides status and diagnostic information for the vehicle system; (e.g., steering, brakes, dump body, engine, transmission, etc.) to navigator **120**. MCM **126** controls the vehicle with the aid of ADEM **128** and EPTC **130**. MCM **126** provides monitoring and diagnostic information to navigator **120** with the aid of VIMS **132**. In addition, VIMS **132** provides monitoring and diagnostic information directly to navigator **120** over a data bus **154**.

ADEM **128** controls the speed or RPM (revolutions per minute) of the vehicle's engine. EPTC **130** controls gear selection in the transmission and ensures that the transmission is in the correct gear. VIMS **132** monitors different systems of the vehicle. ADEM **128**, EPTC **130** and VIMS **132** are available from Caterpillar Inc. of Peoria, Ill. In addition, ADEM **128**, EPTC **130** and VIMS **132** are available as standard equipment on many of Caterpillar's vehicles. However, as discussed below, ADEM **128** and EPTC **130** have been modified in accordance with the present invention to receive controlling inputs from MCM **126** as well as the standard operator inputs from an accelerator pedal and a shift cane, respectively.

Autonomous Operation

To achieve autonomous operation of the vehicle, the steering angle request and the speed request from navigator **120** must be answered by adjusting the steering angle and speed of the vehicle. MCM **126** compares the speed requested by navigator **120** with the actual vehicle speed and adjusts the vehicle speed, if required, by sending appropriate signals to ADEM **128**, EPTC **130** and the vehicle's braking system. MCM **126** communicates these instructions to ADEM **128** and EPTC **130** over a data link **134**. In addition, VIMS **132** monitors the status of ADEM **128** and EPTC **130** over and provides monitored parameters to MCM **126** over data link **134**. In the preferred embodiment, data link **134** is a serial data bus such as a CAT Data Link, available from Caterpillar Inc.

MCM **126** communicates an engine RPM control signal to ADEM **128** over data link **134** to control engine speed. A second engine RPM control signal is also sent to ADEM **128** over a redundant line **136**.

MCM **126** communicates a transmission control signal to EPTC **130** over data link **134** to select the top gear and direction (i.e., forward or reverse) of the transmission. The vehicle has an automatic transmission which is controlled by EPTC **130**. The transmission control signal limits the top gear which may be used by the transmission and selects the direction of travel for the vehicle.

In conjunction with controlling vehicle speed, MCM **126** controls the braking system. In the preferred embodiment of the invention, the vehicle braking system includes a parking brake, a service brake/retarder system, and a secondary brake. The parking brake is a spring applied brake which requires air pressure to be released. Conversely, the service brake/retarder is spring released and requires air pressure to be applied. The secondary brake is similar to the service brake, but operates on a separate air reservoir. The parking brake is used for holding the truck when it is not in use and effects only the rear wheels. The service brake/retarder acts on both front and rear axles. The secondary brake actuates the service brake on the front axle and the parking brake on the rear axle.

MCM **126** controls these different brakes directly via control line **138** which actuates solenoid valves to control air pressure in the three systems. For example, when navigator **120** requests a speed lower than the present speed, MCM **126** decides whether the lower speed should be achieved by reducing engine RPM and/or by applying the service brakes. If braking is required, MCM **126** applies the brake in a smooth manner to avoid locking up the wheels.

In response to the steering angle request from navigator **120**, MCM **126** directly controls the vehicle's steering by sending right steer and left steer signals **140** to solenoids which control steering.

In the preferred embodiment of the invention, autonomous vehicle system **100** is used to implement an autonomous haulage system. Using a number of dump trucks (such as the Caterpillar 777C), the haulage system is configured to carry a material such as rock from an excavation site to a crusher site. To permit fully autonomous operation of the vehicle, MCM **126** controls other features of the vehicle, such as dumping of the truck body. MCM **126** produces a dump signal **142** which actuates the hydraulic system of the vehicle to raise and lower the vehicle body. For safety considerations, MCM **126** also controls auxiliary functions of the vehicle such as the horn, lights and backup alarm via an auxiliary control line **144**.

Thus, during autonomous operation, MCM **126** indirectly controls the engine and transmission via ADEM **128** and EPTC **130**. MCM **126** directly controls the vehicle's braking systems, steering, body (i.e., raise or lower), lights (including head lights and autonomous operation strobe warning lights), horn and back-up alarm.

Manual Operation

MCM **126** implements autonomous operation of a vehicle. It is desirable, however, to also permit manual operation of the vehicle. In a manual mode of operation, the autonomous control features should be transparent and not affect normal functioning of the vehicle. Moreover, for safety, switching between an autonomous mode of operation and a manual mode of operation must be tightly controlled so that the vehicle remains in control at all times. The structure., and operation of MCM **126** which implements these features of the invention are described below.

MCM **126** permits manual operation by relinquishing control of the vehicle subsystems to an operator. In manual mode, ADEM **128** receives the speed request signal from an operator actuated throttle or accelerator pedal **144**. Similarly, EPTC **130** receives top gear selection and direction commands from a shift cane **146** controlled by the operator. Brakes and steering are manually controlled by the operator using a conventional steering wheel and brake pedal. The body is controlled by a switch which actuates a solenoid in the hydraulic system.

During manual operation, MCM **126** will continue to monitor system parameters but will not interfere with control of the vehicle in any way.

Transitioning Between Manual and Autonomous Modes of Operation

MCM **126** defaults to manual mode at power-up. Manual mode is indicated to ADEM **128** and EPTC **130** via an auto/manual select signal sent over an auto/manual control line (AMCL) **150**. For example, AMCL **150** is pulled HIGH by ADEM **128** and EPTC **130**. When AMCL **150** is high, manual mode is indicated to ADEM **128** and EPTC **130**. If autonomous mode is desired, MCM **126** will indicate this to ADEM **128** and AMCL **150** by pulling AMCL **150** LOW.

Transition into autonomous mode will only take place if the following conditions are met:

(1) vehicle speed is zero;

(2) parking brake is on;

(3) shift cane **146** is in neutral;

(4) a first auto/manual switch (located in the cab of the vehicle) is switched to autonomous mode; and

(5) a second auto/manual switch (located near the ground on, for example, the front bumper of the vehicle) is switched to autonomous mode.

If these five conditions are met, MCM **126** will send an auto enable signal to navigator **120** over data bus **152**. If navigator **120** is satisfied that all systems are functioning properly (based on status information provided by MCM **126** and VIMS **154**), navigator **120** will send an auto mode signal back to MCM **126**. Upon receipt of the return auto mode signal from navigator **120**, MCM **126** will enter the autonomous mode. This involves MCM **126** switching ADEM **128** and EPTC **130** into autonomous mode by placing the proper signal on AMCL **150** (e.g., by pulling AMCL **150** low). The vehicle controls (e.g., ADEM **128** and EPTC **130**) will then be ready to receive instructions from MCM **126**, which in turn waits to receive instructions from navigator **120**.

Once the vehicle is in autonomous mode, it will not switch back to manual mode until several conditions exist. These conditions reduce the possibility of the vehicle coming out of autonomous mode at an undesired time or condition, e.g., while the vehicle is in motion. Before the vehicle can switch from autonomous mode to manual mode, the following conditions must exist:

(1) vehicle speed is zero;

(2) parking brake is on;

(3) shift cane **146** is in neutral;

(4) engine RPM is at low idle; and

(5) both the first and second auto/manual switches are in the manual position.

When these conditions exist, MCM **126** will place ADEM **128** and EPTC **130** in manual mode via AMCL **150**. MCM **126** will also de-actuate all solenoid drivers used to control other functions of the vehicle, such as the body, auxiliary functions, brakes and steering.

FIG. **2** is a simplified block diagram illustrating the steps followed in transitioning between manual operation and autonomous operation. Manual operation is indicated at block **202**. Autonomous operation is indicated at block **214**. As indicated above, manual operation **202** is the default of MCM **126** upon power-up. If it is desired to switch into the autonomous operation mode and each of the conditions listed above is met, MCM **126** will cycle through steps **204–212** before reaching autonomous mode **214**.

First, in a step **204**, a speed self-test is executed. The speed self-test checks data link **134** to assure that it is operating properly and that ADEM **128** and EPTC **130** can be controlled by MCM **126**. In addition, MCM **126** checks for brake pressure and assures that the brakes can be controlled. Next, in a step **206**, a steering self-test is performed. In the steering self-test, the wheels of the vehicle are moved to assure that steering can be controlled, and that the change in the steering angle can be sensed via position sensors (not shown).

In a step **208**, a wait state is entered. In the preferred embodiment, a five second pause is executed. At the beginning of the pause, the horn is honked and strobe lights are turned ON to warn any person near the vehicle that autonomous operation is being enabled. Thereafter, the vehicle enters a ready mode as indicated at step **210**. In ready mode, MCM **126** is in control of the speed and the steering of the vehicle. The steering angle is set to zero degrees and the speed is maintained at zero miles per hour. The vehicle will remain in ready state until a valid command is received from navigator **120**.

Once a valid command is received, MCM **126** will enter a second wait state as indicated at step **212**. The second wait state is similar to the first. The horn is again honked and the strobe lights remain on from the first wait state. At the conclusion of this second wait state, autonomous mode begins as indicated at step **214**.

If the speed self test at step **204** or the steering self test at step **206** fails, or if either of the auto/manual control

switches are toggled to manual mode during any of steps **208–212**, MCM **126** will abort the changeover to autonomous operation and will proceed directly to a step **216** which performs an orderly transition back to manual operation **202**. The orderly transition or shut-down includes assuring that the vehicle speed is zero, the parking brake is on, the transmission is in neutral. The vehicle will stay in the transition mode until both of the auto/manual control switches are switched to manual mode. At this point, the vehicle can then return to manual operation as indicated in step **202**.

Operator Intervention in Autonomous Mode

In the event that an operator is present in the vehicle while the vehicle is in autonomous mode, provisions have been provided for receiving and acting on certain manual operator inputs. An operator can alter the vehicles direction by manually operating the steering wheel. The cumulative effect on the steering angle will be dependent on the sum of the steering commands coming from the operator and the commands coming from MCM **126**.

The operator will not be able to increase engine RPM. Because ADEM **128** is in the autonomous mode, the accelerator pedal will have no effect. Similarly, the operator will not be able to change the transmission top gear, because the shift cane position will be ignored by the EPTC **130**. The operator can stop the vehicle by placing the first auto/manual control switch (the one located in the cab of the vehicle) into the manual position. This causes MCM **126** bring the vehicle to a controlled stop on the path.

An operator can increase the vehicle's deceleration by stepping on the service brake pedal or pulling on a retarder handle within the vehicle cab. MCM **126** will detect that the brakes are being manually applied by the changes in pressure in the braking system and will begin to slow the vehicle. Moreover, manual actuation of the service brake increases the applied braking force.

MCM **126**

FIG. **3** is a block diagram of MCM **126**. MCM **126** includes a microprocessor **302** (e.g., a Motorola 68332 microprocessor), a random access memory (RAM) **304**, an erasable programmable read only memory (EPROM) **306**, a flash electrically erasable programmable read only memory (EEPROM) **308**, an input buffer **310**, a communications module **312**, a low level output driver **314** and a high level output driver **316**. Each of these modules is connected via a 16 bit data bus **318**. The programs which control operation of MCM **126** are stored in EPROM **306** and are executed by microprocessor **302**. EEPROM **308** is used to store parameters used by the programs. These parameters may be changed to tune MCM **126** for operation on different vehicles.

Input buffer **310** receives MCM input signals from the various switches and sensors as indicated at line **309**. For example, input buffer **310** receives a speed indication from a vehicle odometer, auto/manual select signals from the auto/manual control switches, and steering angle indications from the steering angle sensors. Processor **302** receives the various inputs from input buffer **310** by reading internal latches of buffer **310** via bus **318**. In addition, a bus **317** provides a direct connection between input buffer **310** and input pins of processor **302**. Bus **317** provides, for example, frequency modulated and pulse width modulated (PWM) signals directly to a timer module of processor **302**. Second RPM control signal **136** is an example of a PWM signal.

Communications module **312** implements three communications ports for MCM **126**. The first port is an RS232 serial communications port used to communicate with navigator **120** as indicated by data bus **152**. The second port is an RS232 serial communications port available for diagnostic monitoring or debugging the operation of MCM **126** as indicated by line **322**. The third port is used for communications with data link **134** using a serial communications protocol.

Low level output port **314** is used to connect AMCL **150** with MCM **126** and to provide the redundant throttle control to ADEM **128** via line **136**. High level output module **316** includes nine high current drivers to control the solenoids which operate vehicle steering, brakes, body dumping, and various auxiliary features.

FIG. **4** is a task diagram illustrating structure and operation of the programs which run on processor **402** to implement the features of MCM **126**. MCM **126** includes a sensor task **402**, a data link task **404**, a speed task **406**, a steering task **408**, an auxiliary task **410**, a navigator communications task **412** and an executive task **416**.

Sensor task **402** monitors various sensors on the vehicle and places status information in a global data store (within RAM **304**) for use by other tasks in MCM **126**. Sensor task **402** also provides the status information to executive task **416**. Sensor task **402** receives much of its information from VIMS **132** over data link **134**. In addition to the information received from VIMS **132**, sensor task **402** monitors the first and second auto/manual switches on the vehicle as well as several independent sensors which have been specifically added to the vehicle to facilitate autonomous operation. These include, for example, resolvers to sense steering angle.

Data link task **404** manages communications between MCM **126** and ADEM **128**, EPTC **130** and VIMS **132** over data link **134**. The information communicated over the data link is provided to executive task **416** and speed task **406**. Speed task **406** generates the engine RPM control signal and the transmission control signal which are communicated to ADEM **128** and EPTC **130** via data link task **404**. In addition, speed task **406** directly controls the body of the vehicle, over line **142**, and the three braking systems of the vehicle over line **138**.

Vehicle speed is controlled in a closed loop fashion. When speed requests are received from navigator **120**, they are compared to the actual vehicle speed as indicated in data store **304**. The actual vehicle speed as indicated in data store **304** is continuously updated by sensor task **402**.

Steering task **408** controls the steering of the vehicle via control line **140**. Steering is controlled in a closed-loop manner by comparing the steering angle indicated in data store **304** with the requested steering angle received from navigator **120**. Auxiliary task **410** controls auxiliary functions of the vehicle such as the horn and lights via an auxiliary control line **144**. Navigator communications task **412** communicates with navigator **120** over line **152** which is a serial communications bus.

Executive task **416** manages operation of all other tasks in MCM **126**. This involves controlling the transition between autonomous and manual operation modes.

EPTC **130**

Control of the actual transmission gear is performed by EPTC **130**. In the manual mode, the position of the cane lever communicates to the EPTC **130** the desired direction of travel in maximum allowable gear. EPTC **130** will shift the transmission through the gears and up to the maximum allowable gear as indicated by the shift lever. EPTC **130** receives the vehicle speed from VIMS **132** over data link **134** to be used in applying its gear shifting strategy. For additional information on manual operation of EPTC **130**,

see Caterpillar Service Manual No. SENR5666, titled "Electronic Programmable Transmission Control (EPTC II) For ICM Transmissions," May 1993, available from Caterpillar, Inc., Peoria, Ill., which is incorporated herein by reference.

When MCM **126** receives an autonomous mode request from navigator **120**, MCM **126** places ADEM **128** and EPTC **130** into the autonomous mode by grounding AMCL **150**. Once in the autonomous mode, EPTC **130** sends a broadcast stop message to MCM **126** over data link **134**. This message tells MCM **126** to stop communications with EPTC **130**. MCM **126** responds by sending a broadcast stop acknowledge message to EPTC **130** over data link **134**. EPTC **130** then sends a broadcast request message to MCM **126** telling MCM **126** to send the transmission control signal. MCM **126** responds by sending a broadcast request response message to EPTC **130** before sending the transmission control signal. The transmission control signal is sent once per second.

This hand shaking between MCM **126** and EPTC **130** prior to the transmission of control signals assures that the communication link is functioning properly. If a failure in data link **134** occurs, EPTC **130** will assume a gear selection of neutral. That is, the transmission will stay in the present gear, or down shift when the vehicle speed so allows, until the vehicle is stopped. When EPTC **130** detects a change on AMCL **150** (e.g., a request to change from autonomous to manual, mode), EPTC **130** will select a gear of neutral and send out a broadcast stop request to MCM **126**. MCM **126** will respond by sending a broadcast request response message. Then, if manual shift cane **146** is in neutral, EPTC **130** will enter manual mode. If manual shift cane **146** is not in neutral, EPTC **130** will hold the transmission in neutral and will remain in that state until neutral is indicated by manual shift cane **146**. Any component problems detected by EPTC **130** are reported to VIMS **132** over data link **134**.

These features of EPTC **131**) are implemented by modifying the programmed microcode in EPTC **130**. Microcode is added to EPTC **130** which operates a layer above the standard algorithm which controls shifting of the transmission. The functionality of the additional microcode is illustrated in the operational flow chart of FIG. **5** which presents a loop which executes every 25 milliseconds.

In FIG. **5**, normal operation of the transmission is indicated at step **514**. All other steps/blocks of FIG. **5** implement the features of the invention which allow EPTC **130** to operate in either a manual mode or an auto mode in conjunction with MCM **126**. These features are now described with reference to the flowchart.

At power-up of EPTC **130**, a reset occurs as indicated at step **502**. After reset, the operating mode of EPTC **130** defaults to manual and a remote gear select (RGS) variable is set to neutral as indicated at step **504**. The remote gear select or RGS variable is the transmission control signal received from MCM **136** over data link **134**. EPTC **130** takes the transmission control signal and stores it in a memory location as a remote gear selection. When EPTC **130** is in manual mode, gear selection is controlled by the shift cane. When EPTC **130** is in auto mode, gear selection is controlled by RGS.

At step **506**, AMCL **150** is checked. If AMCL **150** indicates manual operation, then the method proceeds to step **508**. In step **508**, a check is made to determine whether this is the first time AMCL **150** is indicating manual mode (i.e., a change from auto mode is occurring). If this is not the first indication of manual mode, then the method proceeds to step **510**. At step **510**, EPTC **130** is checked to determine whether EPTC is actually operating in auto or manual mode. If EPTC **130** is operating in manual mode, then the manual shift lever or cane is checked for gear position at step **512**. The transmission is then shifted according to the normal shifting algorithm of step **514**. The method then returns to step **506**. As long as AMCL **150** continues to indicate manual mode, EPTC **130** will continue to operate in this loop in which gear selection is taken from the manual shift cane.

If it is determined, at step **508**, that this is the first time AMCL **150** has indicated manual mode (i.e., a change from auto to manual is occurring), then the method proceeds to step **530**. At step **530**, a broadcast stop message is transmitted to MCM **126** over data link **134** to initiate a change from auto mode to manual mode as discussed above. At step **532**, the remote gear select variable is checked to determine whether it indicates neutral. If neutral is not indicated, a fault code indicating an invalid transition from auto mode to manual mode is sent to MCM **126** over data link **134**. Then, at step **536**, the manual shift cane is checked to determine whether it is in neutral. If neutral is indicated, then EPTC **130** is set to manual mode in step **538**. If the cane does not indicate neutral, then the remote gear select variable is set to neutral and a fault code for an invalid transition is sent to MCM **126** over data link **134** at step **540**. If, at step **510**, it is determined that EPTC **130** is in auto mode, then the method proceeds to step **536** and continues as discussed above.

Thus, when it is determined at step **506** that AMCL **150** is indicating manual mode, EPTC **130** will take a desired top gear indication from the manual shift cane as indicated at step **512**. Steps **508**, **530**, **532**, **534**, **536**, **538**, and **540** assure that transition from auto mode to manual mode is done in an orderly fashion as outlined above. These steps also ensure that a fault on AMCL **150** will not inadvertently place EPTC **130** in manual mode.

If, at step **506**, it is determined that AMCL **150** indicates autonomous operation, then the method proceeds to step **516**. At step **516**, it is checked to determine whether this is the first time that AMCL **150** has indicated autonomous operation (i.e., a transition from manual to auto is occurring). If yes, then the method proceeds to step **518** where EPTC **130** sends a broadcast request signal to MCM **126** to initiate the signal handshaking (discussed above) which assures proper functioning of the communication link between MCM **126** and EPTC **130**. In addition, at step **518**, EPTC **130** sets the remote gear select (RGS) variable to neutral and sets the EPTC **130** mode to auto.

A remote gear selection is generally received three times per second from MCM **126**. This is tested at step **520**. If a remote gear selection has not been received in the last three seconds, then a fault condition is indicated to MCM **126** over data link **134** (CDL or Cat Data Link in FIG. **5**) at step **522**. In addition, the remote gear select is set to neutral. The method then proceeds to step **514** where the transmission is shifted in accordance with the standard shifting algorithm. If a fault condition was indicated at step **522**, then MCM **126** will reduce engine speed while the RGS of neutral causes EPTC **130** to downshift until the transmission is in neutral and the vehicle can be stopped.

ADEM **128**

ADEM **128** is responsible for governing the speed or RPM of the vehicle's engine. In manual mode, manual throttle or accelerator pedal **144** provides an RPM request which is compared to the actual RPM of the engine. ADEM **128** then adjusts injector fuel delivery to make the actual RPM equal the desired RPM. For additional information on manual operation of ADEM **128**, see Caterpillar Electronic

Troubleshooting Manual No. SENR5191-02, titled "3508 EUI Engine," June 1994, available from Caterpillar, Inc., Peoria, Ill., which is incorporated herein by reference.

When MCM **126** receives a autonomous mode indication from navigator **120**, MCM **126** places ADEM **128** into autonomous mode via AMCL **150**. Once in autonomous mode, ADEM **128** will ignore the manual throttle control and accept engine speed command signals from MCM **126**. MCM **126** computes a desired engine RPM based on the speed request from navigator **120**. The desired RPM is then sent to ADEM **128** over data link **134**. Similar to EPTC **130**, ADEM **128** handshakes signals with MCM **126** prior to opening communications for RPM request signals. For example, when ADEM **128** first detects a manual-to-autonomous status change request on AMCL **150**, ADEM **128** enters autonomous mode and then sends a broadcast stop command over data link **134**. MCM **126** stops communications with ADEM **128** and responds to the, broadcast stop command. MCM **126** then responds with a broadcast stop acknowledgement message. ADEM **128** then sends a broadcast request message, asking MCM **126** for RPM request signals. MCM **126** responds by sending a broadcast request response message and then by sending desired RPM signals once per second. ADEM **128** receives the speed request signals from MCM **126** over the data link. In addition, however, a redundant speed request signal is also generated by MCM **126** and sent to ADEM **128** over a dedicated wire **136**. This redundant signal can be used by ADEM **128** if the speed request signal is not sent on data link **134**. If both signals are absent, ADEM **128** will set the engine to low idle and communicate the loss of communications to VIMS **132**.

When ADEM **128** detects the request to change from autonomous to manual mode on AMCL **150**, ADEM **128** sends a broadcast stop request to MCM **126** over data link **134**. MCM **126** responds with a broadcast stop acknowledgement message. ADEM **128** then begins reading the signal coming from the manual throttle **144**. If the manual throttle **144** requests low idle, ADEM **128** fully enters manual mode. If the signal is not low idle, ADEM **128** will stay in autonomous mode and set the speed at low idle and will not return fully to manual mode until manual throttle **144** indicates a speed of low idle.

FIG. **6** illustrates high level operation of ADEM **128** according to the invention. As with EPTC **130**, ADEM **128** has been modified to add microcode which operates a layer above the standard algorithm which controls engine RPM. The functionality of the additional microcode is illustrated in the operational flow chart of FIG. **6** which presents a loop which executes every 15 milliseconds. The remaining steps of FIG. **6** implement the features of the invention which allow ADEM **128** to be controlled by MCM **126**.

In FIG. **6**, normal operation of the engine is indicated at step **614**. All other steps/blocks of FIG. **6** implement the features of the invention which allow ADEM **128** to operate in conjunction with MCM **126**. These features are now described with reference to the flowchart.

At power-up of ADEM **128**, a reset occurs as indicated at step **602**. After reset, the operating mode of ADEM **128** defaults to manual and a desired RPM variable is set to low idle (LI) as indicated at step **604**. The desired RPM variable is the engine RPM control signal communicated to ADEM **128** by MCM **126** over data link **134**. ADEM **128** takes the engine control signal and stores it in a memory location as a desired RPM or DRPM. When ADEM **128** is in manual mode, engine speed is controlled by the manual accelerator pedal. When ADEM **128** is in auto mode, engine speed is controlled by DRPM.

At step **606**, AMCL **150** is checked. If AMCL **150** indicates manual operation, then the method proceeds to step **608**. In step **608**, a check is made to determine whether this is the first time AMCL **150** is indicating manual mode (i.e., a change from auto mode is occurring). If this is not the first indication of manual mode, then the method proceeds to step **610**. At step **610**, ADEM **128** is checked to determine whether it is actually operating in auto or manual mode. If ADEM **128** is operating in manual mode, then the manual accelerator pedal is checked for position at step **612**. The engine RPM is then controlled according to the normal engine RPM algorithm of step **614**. The method then returns to step **606**. As long as AMCL **150** continues to indicate manual mode, ADEM **128** will continue to operate in this loop in which engine RPM is taken from the manual accelerator pedal.

If it is determined, at step **608**, that this is the first time AMCL **150** has indicated manual mode (i.e., a change from auto to manual is occurring), then the method proceeds to step **630**. At step **630**, a broadcast stop message is transmitted to MCM **126** over data link **134** to initiate a change from auto mode to manual mode as discussed above. At step **632**, the DRPM variable is checked to determine whether it indicates low idle or LI. If low idle is not indicated, a fault code indicating an invalid transition from auto mode to manual mode is sent to MCM **126** over data link **134**. Then, at step **636**, the manual accelerator pedal is checked to determine whether it is in a low idle position. If low idle is indicated, then ADEM **128** is set to manual mode in step **638**. If the pedal does not indicate low idle, then the DRPM variable is set to low idle and a fault code for an invalid transition is sent to MCM **126** over data link **134** at step **640**. If, at step **610**, it is determined that ADEM **128** is in auto mode, then the method proceeds to step **636** and continues as discussed above.

Thus, when it is determined at step **606** that AMCL **150** is indicating manual mode, ADEM **128** will take a desired RPM from the manual accelerator pedal as indicated at step **612**. Steps **608**, **630**, **632**, **634**, **636**, **638**, and **640** assure that transition from auto mode to manual mode is done in an orderly fashion as outlined above. These steps also ensure that a fault on AMCL **150** will not inadvertently place ADEM **128** in manual mode.

If, at step **606**, it is determined that AMCL **150** indicates autonomous operation, then the method proceeds to step **616**. At step **616**, it is checked to determine whether this is the first time that AMCL **150** has indicated autonomous operation (i.e., a transition from manual to auto is occurring). If yes, then the method proceeds to step **618** where ADEM **128** sends a broadcast request signal to MCM **126** to initiate the signal handshaking (discussed above) which assures proper functioning of the communication link between MCM **126** and ADEM **128**. In addition, at step **618**, ADEM **128** sets the DRPM variable to low idle and sets the ADEM mode to auto.

A DRPM signal is generally received three times per second from MCM **126**. This is tested at step **620**. If a remote gear selection has not been received in the last three seconds, then a data link fault condition is indicated to MCM **126** over data link **134** (CDL or Cat Data Link in FIG. **6**) at step **622**. Then, at step **624**, the method checks to see whether the second engine RPM control signal (a PWM or pulse width modulated signal received from MCM **126** over line **136**) is present at ADEM **128**. If the second or PWM engine RPM control signal is present, then the method uses the PWM signal as the DRPM at step **626**. If the second or PWM engine RPM control signal is not present, then a

PWM fault condition is indicated to MCM **126** over data link **134** and the DRPM is set to low idle at step **628**.

The method then proceeds to step **614** where the engine is shifted in accordance with the standard shifting algorithm. If fault conditions were indicated at steps **622** and **628**, then ADEM **128** will reduce the engine speed to low idle as set forth in step **628**, and MCM **126** will cause the vehicle to come to a stop. If a fault condition is indicated only at step **622** and not step **628**, then the vehicle may continue to operate using the second engine RPM control signal (the PWM signal) to set the DRPM.

VIMS **132**

Monitoring the status of the various vehicle systems is provided by VIMS **132**. VIMS **132** gathers information by reading dedicated sensors on the vehicle and also by receiving information from ADEM **128** and EPTC **130** over data link **134**. VIMS uses the collected information to determine a machine warning level. The machine warning level indicates the highest fault level present on the vehicle. It transmits this information directly to navigator **120** via line **154**. VIMS **132** also provides this information to MCM **126** via data link **134**. Navigator **120** may stop the vehicle by sending a zero speed request to MCM **126**. In addition, if a serious fault condition exists, MCM **126** may stop the vehicle directly.

Sample warning level indicators include the following:

Level I: An example of a Level I warning is a fluid level out of normal operating range. In the case of a Level I warning, the vehicle continues full autonomous operation. However, the navigator indicates to the fleet manager that attention is needed to correct the condition in due course.

Level II: An example of a Level II warning is an excessive engine operating temperature. The Level II warning indicates that a condition exists that will cause serious damage to the vehicle if operation is not changed.

Level III: Examples of Level III warnings include low air pressure, low oil pressure and lack of coolant flow. In the case of a Level III warning, the vehicle should be stopped without delay. To accomplish this, navigator **120** commands MCM **126** to stop the vehicle immediately.

The parameters monitored by VIMS **132** include, for example, transmission charge filter, fuel filter, coolant flow, steering flow, brake master cylinder overstroke, engine oil level, transmission oil temperature, torque converter oil temperature, after cooler temperature, brake oil temperature, primary system air pressure, secondary system air pressure, steering fluid temperature, right turbo temperature, left turbo temperature, cab air temperature, left rear strut pressure, right rear strut pressure, left front strut pressure, right front strut pressure, speed, gear position, parking brake, body raise, engine RPM, engine oil pressure, atmospheric pressure, right turbo inlet pressure, jacket water temperature, rack position, boost pressure, fuel flow, and air filter restriction.

For additional information on VIMS **132**, see Caterpillar Service Manual No. SENR6059, titled "Vital Information Management System (VIMS)," July 1993, available from Caterpillar, Inc., Peoria, Ill., which is incorporated herein by reference.

While the invention has been particularly shown and described with reference to several preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A system for controlling autonomous operation of a vehicle in response to a speed request signal and a steering angle request signal from a navigator and for selectively allowing manual operation of the vehicle, the system comprising:

machine control means for receiving an auto/manual select signal, said speed request signal and said steering angle request signal and for producing a speed control signal, a steering angle signal, and an auto/manual control signal;

speed control means for controlling the speed of the vehicle in response to said speed control signal and an operator input when said auto/manual control signal indicates autonomous operation and in response only to said operator input when said auto/manual control signal indicates manual operation; and

steering control means for controlling the steering angle of the vehicle in response to said steering angle control signal and an operator input when said auto/manual control signal indicates autonomous operation and in response only to said operator input when said auto/manual control signal indicates manual operation.

2. The system of claim **1**, wherein said machine control means comprises:

a processor; and

program means for enabling said processor to control autonomous operation of the vehicle said program means including

navigator communications means for enabling said processor to receive said speed request signal and said steering angle request signal from the navigator,

sensor means for enabling said processor to receive a measured steering angle, a measured speed and said auto/manual select signal,

speed control signal means for enabling said processor to generate said speed control signal, in response to said speed request signal and said measured speed to control an engine, a transmission and a brake disposed in the vehicle and for enabling said processor to control the dumping of a body of the vehicle,

steering means for enabling said processor to generate said steering angle control signal in response to said steering angle request signal and said measured steering angle,

data link means for enabling said processor to communicate said speed control signal to an engine controller disposed in the vehicle and to communicate said steering control signal to a transmission controller disposed in the vehicle, and

executive means for enabling said processor to supervise said program means and to generate said auto/manual control signal in response to said auto/manual select signal.

3. The system of claim **2**, wherein said program means further comprises

auxiliary means for enabling said processor to control auxiliary functions on the vehicle.

4. A system for controlling autonomous operation of a vehicle in response to speed and steering angle request signals from a navigator and for selectively allowing manual operation of the vehicle, the system comprising:

machine control means for receiving an auto/manual select signal, said speed request signal and said steering angle request signal and for producing an engine RPM

control signal, a transmission control signal, a brake control signal, a steering angle control signal, and an auto/manual control signal;

engine RPM control means for controlling an RPM of a vehicle engine in response to said RPM control signal when said auto/manual control signal indicates autonomous operation and in response to an operator input when said auto/manual control signal indicates manual operation; and

transmission control means for controlling a gear selection in a vehicle transmission in response to said transmission control signal when said auto/manual control signal indicates autonomous operation and in response to an operator input when said auto/manual control signal indicates manual operation.

5. The system of claim **7**, wherein said machine control means comprises:

a processor; and

program means for enabling said processor to control autonomous operation of the vehicle, said program means including

navigator communications means for enabling said processor to receive said speed request signal and said steering angle request signal from the navigator,

sensor means for enabling said processor to receive a measured steering angle, a measured speed and said auto/manual select signal,

speed control means for enabling said processor to generate said RPM control signal, said transmission control signal and said brake control signal in response to said speed request signal and said measured speed,

steering means for enabling said processor to generate said steering angle control signal in response to said steering angle request signal and said measured steering angle, and

executive means for enabling said processor to supervise said program means and to generate said auto/manual control signal in response to said auto/manual select signal.

6. The system of claim **5**, wherein said program means further comprises:

data link means for enabling said processor to communicate said engine RPM control signal to said engine RPM control means and for enabling said processor to communicate said transmission control signal to said transmission control means.

7. The system of claim **6**, wherein said program means further comprises:

auxiliary means for enabling said processor to control auxiliary functions on the vehicle.

8. A system for controlling autonomous operation of a vehicle in response to a speed request signal and a steering angle request signal generated by a navigator, comprising:

a processor; and

program means for enabling said processor to control autonomous operation of the vehicle, said program means including

navigator communications means for enabling said processor to receive the speed request signal and the steering angle request signal from the navigator, p1 sensor means for enabling said processor to receive a measured steering angle, a measured speed and an auto/manual select signal,

executive means for enabling said processor to supervise said program means and to generate an auto/manual control signal in response to said auto/manual select signal,

speed control means for enabling said processor to control vehicle speed in response to the speed request signal and said measured speed only when said auto/manual control signal indicates autonomous operation, wherein said speed control means includes

means for generating an engine RPM request signal in response to the speed request signal to adjust the RPM of an engine disposed in the vehicle,

means for generating a transmission control signal in response to the speed request signal to adjust gear selection of a transmission disposed in the vehicle, and

means for generating a brake control signal in the vehicle in response to the speed request signal to decrease the speed of the vehicle by applying a braking action on a brake disposed in the vehicle, and

steering means for enabling said processor to control vehicle steering in response to the steering angle request signal and said measured steering angle only when said auto/manual control signal indicates autonomous operation.

9. The system of claim **1**, wherein said program means further comprises:

data link means for enabling said processor to communicate said engine RPM request signal to an engine controller disposed in the vehicle and for enabling said processor to communicate said transmission control signal to a transmission controller disposed in the vehicle.

10. The system of claim **9**, wherein said speed control means further comprises:

means for controlling a dump position of a body of said vehicle.

11. The system of claim **10**, wherein said program means further comprises:

auxiliary means for enabling said processor to control auxiliary functions on the vehicle.

12. The system of claim **5**, wherein said auxiliary means comprises:

means for switching power to lights disposed in the vehicle; and

means for sounding a horn disposed in the vehicle.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,469,356

DATED : November 21, 1995

INVENTOR(S) : Mark R. Hawkins et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Claim 5, column 15, line 16: change "7" to --4--.

Claim 8, Column 16, line 6, delete "pl".

Claim 9, column 16, line 34: change "1" to --8--.

Claim 12, column 16, line 51: change "5" to --11--.

Signed and Sealed this

Twenty-fourth Day of September, 1996

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks